PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

An endoscopy capsule for well-confined and angle-controlled photothermal mucosa ablation

Türker Burhan, Merve, Tozburun, Serhat

Merve Türker Burhan, Serhat Tozburun, "An endoscopy capsule for well-confined and angle-controlled photothermal mucosa ablation," Proc. SPIE 11958, Optical Interactions with Tissue and Cells XXXIII; and Advanced Photonics in Urology, 119580C (2 March 2022); doi: 10.1117/12.2609602

SPIE.

Event: SPIE BiOS, 2022, San Francisco, California, United States

An endoscopy capsule for well-confined and angle-controlled photothermal mucosa ablation

Merve Turker Burhan*[a,b] and Serhat Tozburun[a,b,c]
[a]Izmir Biomedicine and Genome Center, Mithatpasa St. 58/5, Balcova, Izmir, Turkey
[b]Izmir International Biomedicine and Genome Institute, Dokuz Eylul University, Balcova, Turkey,
[c]Department of Biophysics, Faculty of Medicine, Dokuz Eylul University, Balcova, Izmir, Turkey

ABSTRACT

As the innermost layer of the gastrointestinal (GI) tract, the mucosa layer has critical importance in carcinogenesis. *Barrett's esophagus* is a pre-cancerous lesion characterized by intestinal metaplasia within the stratified squamous epithelium of esophageal mucosa. Mucosal lesions that are not adequately treated tend to enlarge and become cancerous tissue over the surface and deeper layers. Although various treatment strategies are available, uncontrolled depth of treatment to eliminate lesions is still challenging. Exceeding the treatment depth may cause adverse effects on the underlying healthy tissue layers, while insufficient treatment depth may cause the lesion to recur. Besides, the inhomogeneity of the distribution of the lesions on the esophageal surface makes it difficult to apply ablation therapy in a single session, requiring more sessions. However, a feasible approach is still needed to perform the desired results in photothermal ablation at a single therapy session. This study demonstrates an endoscopy capsule that provides well-confined and angle-controlled photothermal mucosal ablation. The capsule consists of three parts: a base that holds a stepper motor and a GRIN lens; a cap that includes gold-coated right-angle prism mirrors; an optically transparent and perforated body for negative pressure unites the base and cap. The mucosa layer is confined to the recessed area of the capsule by negative pressure delivered through holes. The laser beam at 1505 nm is rotated with a constant speed and defined rotation angles for circumferential photothermal ablation.

Keywords: Photothermal mucosa ablation, controlled therapy depth, endoscopy capsule

1. INTRODUCTION

The GI tract consists of four tissue layers, serosa (adventitia), muscularis externa, submucosa, and mucosa from outside to inside. Serosa is the outermost layer which is mainly composed of connective tissue. Muscularis externa lies between the serosa and submucosa. It has circular and longitudinal smooth muscle layers responsible for peristaltic movements. The submucosa layer is an irregular, dense, or loose connective tissue containing blood vessels, lymphatics, and nerve network.

The mucosa layer as the innermost layer of the GI tract is quite critical. Malignancies of the GI tract such as esophageal cancer, gastric cancer, colon cancer, and rectum cancer are leading causes of death worldwide and emerge as precancerous lesions on mucosa layer[1]. For example, *Barrett's esophagus*, characterized by intestinal metaplasia within the stratified squamous epithelium of esophageal mucosa, is a precancerous lesion. If it is not treated or insufficiently treated, it tends to expand toward deeper tissue layers, becoming cancerous tissue. Therefore, early diagnosis and treatment of precancerous lesions have a crucial impact on prognosis, thereby the patients' quality of life. Ablation therapy is a commonly preferred treatment strategy for mucosal lesions. It is a minimally invasive procedure mainly based on removing target lesions by thermal damage. Several different techniques[2-5], such as multipolar electrocoagulation, argon plasma coagulation, cryotherapy, radiofrequency ablation, and photothermal ablation, are used for ablation therapy.

Mucosa thickness varies between 0.4 mm to 1.0 mm for different parts of the GI tract and person from person[6,7]. However, fixed therapy depth provided by commonly used ablation techniques could not meet the mucosal thickness. Thus, inadequate therapy depth may lead to the recurrence of a lesion, whereas excessive therapy depth may damage healthy tissue underlying the lesion. Besides, although the lesion initially emerges superficially, it may proceed on the surface or through deeper layers or both over time. Recently, we demonstrated that fiber tip and laser wavelength could effectively control therapy depth in an ex-vivo sheep esophagus model[8]. However, complete elimination of mucosal lesions in wide surface before spreading is the primary purpose of ablation therapy. Therefore, well-confined therapy depth has utmost importance for efficient treatment.

* merve.turker@msfr.ibg.edu.tr; phone 90 232 299-5100; fax 90 232 277-6353

Optical Interactions with Tissue and Cells XXXIII; and Advanced Photonics in Urology
edited by Bennett L. Ibey, Norbert Linz, Proc. of SPIE Vol. 11958, 119580C

1605-7422 · doi: 10.1117/12.2609602

This study presents an endoscopy capsule that provides photothermal mucosa ablation with well-confined therapy depth and angle control. The capsule consists of three parts: base, body, and cap, which includes a GRIN lens, a stepper motor, and gold-coated right-angle prism mirrors. The GRIN lens and mirrors orient the laser beam. The stepper motor provides angular control on laser beam rotation. An optically transparent and perforated body allows the non-contact interaction of the laser beam with the tissue while restricting the tissue depth exposed to the laser beam by delivering negative pressure through its holes. Thus, the mucosa layer is confined to the recessed area of the capsule during the photothermal ablation process. The laser beam at 1505 nm is rotated with a constant speed and defined rotation angles for angle-controlled photothermal ablation.

2. METHODOLOGY

Figure 1 shows the developed endoscopy capsule having three main parts: base, body, and cap. The base holds a fiber-coupled GRIN lens (Go4Fiber, Kowloon, Hong Kong) to transmit and collimate the laser beam and a stepper motor (Faulhaber Micromo, Florida, United States) for rotation. Cap holds two gold-coated right-angle prism mirrors (Thorlabs, New Jersey, United States) to direct the laser beam to another gold-coated right-angle prism mirror fixed on the shaft of the stepper motor. The body is an optically transparent part of the capsule that unites the base and cap. Additionally, it is perforated to apply negative pressure, which helps pull the mucosa layer into the recessed area.

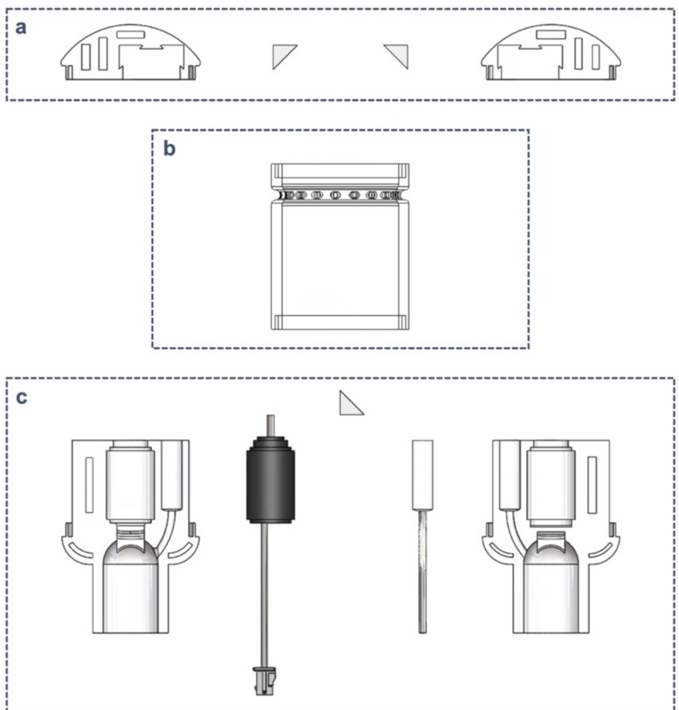

Figure 1. Cross-sectional view of the endoscopy capsule for well-confined and angle-controlled photothermal mucosa ablation. It consists of three parts: (a) a cap that holds gold-coated right-angle prism mirrors; (b) an optically transparent and perforated body; (c) a base that holds a stepper motor and a GRIN lens.

Fiber coupled GRIN lens at the base part transmits and collimates the laser beam towards the mirror which is align with the lens. This mirror reflects the laser beam 90º to another mirror placed oppositely, to orient laser beam towards the other mirror that on the top of stepper motor. The last mirror reflects the laser beam perpendicular to body part through the cavity. Stepper motor rotates the transmitted laser beam between 0º-360º. The holes on body parts apply negative pressure on site of cavity to pull the mucosa layer of tissue.

The critical point of the optical path inside the capsule is that the laser beam is centered. Besides, the beam trapped within the cavity of the body part through the circumferential motion. Figure 2 shows the alignment setup of optical and mechanical components of the capsule. The verticality of the GRIN lens and the stepper motor, and the position of the mirror placed on the stepper motor shaft were controlled by the alignment of the mirrors on the cover. After the components in the base part aligned adequately, the mirrors in the cap were fixed, and all capsule parts were united.

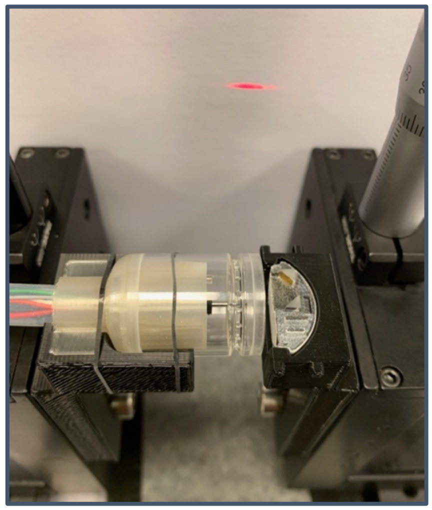

Figure 2. A setup to control the alignment of optical and mechanical components of the capsule. The perpendicularity of the GRIN lens and stepper motor with the proper distance between each component provides a laser beam path to obtain a circular line inside the cavity of the body part.

3. RESULTS

Figure 3 shows the cross-sectional view of the cap part after the gold-coated right-angle prism mirrors were placed and fixed their nests in the cap. A diode laser at a wavelength of 660 nm was used as an aiming beam to control alignment. A reflected laser beam through the mirrors of the optical path inside the endoscopy capsule reached the cavity of the body part and could be controlled by the stepper motor's rotation. Figure 4 represents the circumferential movement by showing the laser beam on the surrounding ring at the positions of 0° (Figure 4a), 90° (Figure 4b), 180° (Figure 4c), and 270° (Figure 4d). Table 1 lists the technical specifications of the endoscopy capsule.

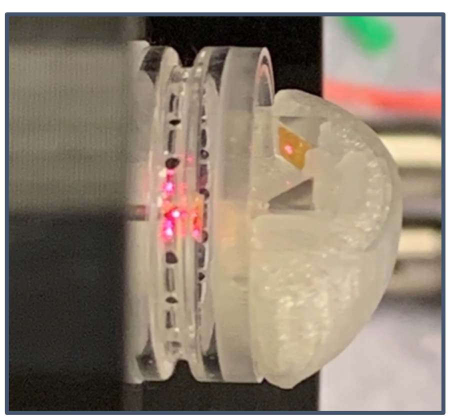

Figure 3. Cross-sectional view of cap part including two gold-coated right-angle prism mirrors. Oppositely placed mirrors reflect the transmitted laser beam on the stepper motor shaft to the third mirror. All mirrors in the capsule reflect the laser beam at 90°.

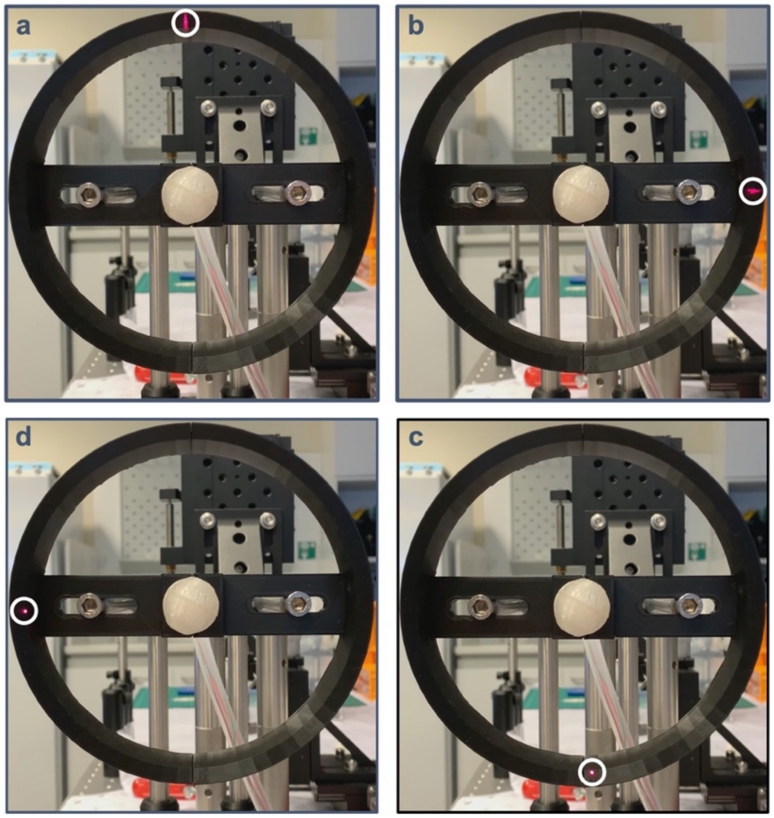

Figure 4. A series of frames demonstrate the circumferential laser beam motion provided by the capsule. A visible diode laser at 660 nm (seen on the black ring) was used as an aiming beam to follow the stepper motor's rotation. (a), (b), (c), and (d) show the laser beam position at 0°, 90°, 180°, and 270°, respectively, as the result of angle-controlled rotational movement.

Table 1. Technical specifications of endoscopy capsule.

Specifications	
Visible Laser Wavelength	660 nm
IR Laser Wavelength	1505 nm
IR Laser Beam Diameter	0.4 mm
IR Laser Maximum Output Power	240 mW
Step Angle of Motor	0.07^{o}
Speed Range of Motor	0.1mm/s – 200 mm/s
Vacuum Range of Capsule	-350 mmHg to -700 mmHg

4. DISCUSSION

As an ablation strategy, photothermal ablation provides an opportunity to restrain excessive therapy depth by using a laser at a near-IR wavelength whose optical penetration depth is coupled with the thickness of the mucosa layer. The capsule design allows transmission of the laser beam to the tissue safely and effectively. Besides, negative pressure controls the therapy depth by restricting the mucosa layer to the capsule body's recessed region. However, a few points should be discussed about this capsule. Although it performs properly during technical investigations, its effectiveness on tissue should be demonstrated with ex-vivo experimental studies. Being consisted of three parts may affect the delivery of negative pressure to tissue if they are not sealed adequately.

5. CONCLUSIONS

This study demonstrates an endoscopy capsule that provides well-confined and angle-controlled photothermal mucosal ablation. This capsule controls therapy depth by defining optical penetration with a near-IR laser and limiting tissue depth with the recessed region using negative pressure. Additionally, angle definition on rotational movement provides more control on the laser beam. This design may hold promise in endoscopy ablation interventions in clinics with further preclinical investigations.

ACKNOWLEDGEMENTS

This work was supported partially by TUBITAK grant No [117E985] and the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No [835907]. Serhat Tozburun was supported by the Turkish Academy of Sciences Young Scientists Award Programme (2018 TUBA GEBIP). Merve Turker Burhan was supported by a Turkish Council of Higher Education 100/2000 doctoral scholarship and by a Fatoş Buyukkuşoğlu Strong Women Award from Arya Women Investment Platform.

REFERENCES

[1] Chung, C-S., Wang, H-P., "Screening for precancerous lesions of upper gastrointestinal tract: from the endoscopists' viewpoint," Gastroenterol. Res. Pract. 2013 681439, 1-18 (2013).

[2] Martinucci, I., de Bortoli, N., Russo, S., Bertani, L., Furnari, M. et al. "Barrett's esophagus in 2016: From pathophysiology to treatment," World J. Gastrointest. Pharmacol. Ther. 7(2), 190-206 (2016).

[3] Garud, S. S., Willingham, F. F., Cai, Q., "Diagnosis and management of Barrett's esophagus for the endoscopist," Therap. Adv. Gastroenterol. 3(4), 227–238 (2010).

[4] Watson, T. J., "Endoscopic therapies for Barrett's neoplasia," J. Thorac. Dis. 6(SUPPL.3), 298-308 (2014).

[5] Kallam, A., Alsop, B. R., Sharma. P., "Limitations of endoscopic ablation in Barrett's esophagus," Expert Rev. Gastroenterol. Hepatol. 9(4), 487–496 (2015).

[6] Hohmann, M., Lengenfelder, B., Kanawade, R., Klämpfl, F. et al. "Measurement of optical properties of pig esophagus by using a modified spectrometer set-up," J. Biophotonics 11(1) (2018).

[7] Ribeiro, S. R., Pinto, P. E. Jr., de Miranda, A. C., Bromberg, S. H. et al. "Weight loss and morphometric study of intestinal mucosa in rats after massive intestinal resection: influence of a glutamine- enriched diet," Rev. Hosp. Clin. Fac. Med. Sao Paulo 59(6), 349-56 (2004).

[8] Tozburun, S., "Superficial photothermal laser ablation (SPLA) of ex-vivo sheep esophagus using a cone-shaped optical fiber tip," J. Biophotonics 13(6), e201960116 (2020).